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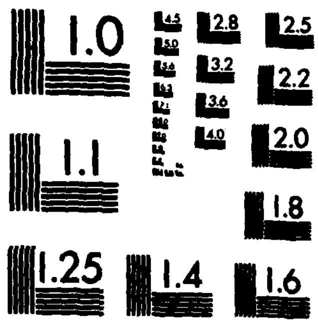
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NONDESTRUCTIVE INSPECTION AND MEASUREMENT

by

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NONDESTRUCTIVE INSPECTION AND MEASUREMENT

Wu Zhun

TAKING WARNING FROM THE CART AHEAD: IF IT OVERTURNS, BE CAREFUL

At a satellite launch site in the space center, thousands of pairs of eyes looked at a carrier rocket (with a gigantic thrust) on the launch platform. Once the countdown stopped, clouds of dark smoke came off the rocket tail. Then waves of thunder like roars were heard as the rocket slowly rose from the launch platform like a long sword piercing the blue sky. After about a dozen seconds, an explosion was unexpectedly heard; then the rocket crashed onto the ground. This was a 16 million US dollar failure, the amount paid by the European Space Agency to the United States for launching the orbit testing satellite I, which cost an additional 25 million launch dollars. A large sum of money went up in smoke because of the engine quality problem of the carrier rocket. There have been many such failures in the record of space flight history, such as the midair destruction of the first Redstone rocket engine due to cracks in the main welding seams of a fuel tank. From incomplete statistics, the successful probability of rocket launch is a little over 90 percent. Through analysis of the launch failure, the case is found to be problem of rocket engine quality and control electronic device quality. For example, the second test failure of the Ariane rocket (developed by joint effort of West European countries) occurred in May

1980. After analyzing the residue from the rocket crash, the failure was found to have been caused by high frequency unstable combustion due to internal engine defects. Obviously, we face limitations in destructive testing on internal rocket quality; these tests are not allowed on many occasions. Therefore, nondestructive inspections and measurements are extensively applied. In order to ensure quality for conducting space flight without failure, in many countries nondestructive inspections and measurements are conducted on various work processes in rocket manufacture, especially for solid fuel rockets. In rocket storage and service procedures, strict monitoring is also conducted on quality integrity. Even in the initial rocket development, the corresponding nondestructive technique of inspection and measurement is developed for quality control and plan of inspection and measurement. In some opinions, if the advanced nondestructive inspection and measurement method can be applied on rocket engines for overall quality control, 70 percent of failures can be reduced, such as those caused by mechanical wear, separation of adhesion, cracks, gas bubbles, material defects, and machining errors. As proved by facts, the launch success rate of spacecraft has been considerably increased because various nondestructive means of inspection and measurement have been effectively adopted.

NONDESTRUCTIVE INSPECTION AND MEASUREMENT AS WELL AS ITS APPLICATIONS

Nondestructive inspection and measurement is a comprehensive science and technology. Under the condition of not damaging materials or components and by utilizing the principles of physics and chemistry as well as electronic technology, we can determine internal and surface defects of materials and components, physical characteristics, and other technical parameters. In the space industry, these inspections include measurements of noncontinuous defects of components made of metals, nonmetals, and composite materials in addition to physical characteristics, thickness, stress, quality of welding seams and gluing, quality of electrical components and material sorting.

The history of development of nondestructive inspection and measurement is quite long. In ancient China, the sound of striking ceramic utensils was used to determine whether there were internal cracks. More than 2000 years ago, the ancient Greek scholar Archimedes also used the principle of water displacement to determine nondestructively what material a crown was made of. With the

progress of time, up to now there have been more than 50 methods of nondestructive inspection and measurement. In addition to the ancient acoustical method for leakage inspection, the main modern methods include supersonic inspection and measurement, testing with rays, and inspection and measurement by using supersonics, rays, infiltration, magnetic powder, and eddy current. Beginning from the 1960s, there have been developments of holographic photography, neutron photography, and inspections and measurements using infrared rays, microwaves, and sound emission.

The principle used for supersonic inspection and measurement is reflection. A shout in a deep gorge will produce a loud echo as the sound wave is reflected upon hitting a barrier. A kind of supersonic wave is produced during a bat's flight; it changes the flight direction upon receiving the reflected supersonic signal from a barrier. Sonar and radar are developed by using this principle. The difference in supersonic inspection and measurement is that sound waves propagate inside the metal material. A supersonic wave detector can inspect existing defects in a metal piece; however, this method is not appropriate to monitor the formed and developed defects (such as development of microcracks) during the operation of parts and components. Then scientists developed a technique of sound transmission. When one lifts one's body by holding a tree branch, it will begin to crack (with a sound "keke") and then break with a sound "kacha" if the tree branch is not strong enough. When a substance begins to break and extend cracks, in most cases sound energy will be liberated. However, generally human ears are unable to hear the supersonic waves; sound emission inspection and measurement utilize the supersonic probe to receive the emitted sound energy produced by an object upon loading.

The nondestructive inspection and measurement technique can not only inspect an object in a static condition, the technique can also monitor an object in a dynamic state. The hydraulic explosion test conducted on a sealed shell container in the manufacturing process of solid-fuel rocket engine utilizes multichannel sound emitting instruments by installing scores of probes on the exterior of the rocket shell. Sound emission signals are produced when the shell begins to crack or cracks are extended. As there are different distances between the sound source and the various probes, the time durations upon

receiving the signals are different. Based on the time difference, positions of defects can be determined. Generally, these tests require the use of a computer.

The application of nondestructive inspection and measurement in the space industry is quite extensive. The technique is almost universally required for raw materials, parts, components, and the finished product of a rocket. For example, the nondestructive technique is used in sorting raw materials and supplies to discard unacceptable materials because various defects will be produced in smelting, casting, forging, welding and heat treatment processes of metals, as well as in synthesis, pouring and extrusion forming of nonmetals. Besides, the technique can inspect cracks, gas bubbles, sand holes, slags, and sites not thoroughly welded inside metal parts, as well as impurities, cavities, gas bubbles, looseness, and separation of adhesion (physical defects) of composite materials. Furthermore, the destructive technique can inspect the quality in the interior of micro-electric parts (such as integrated circuits and electronic components) and various welding and connection pieces of a rocket. The application of nondestructive inspection and measurement also includes the measurement of physical and mechanical characteristics of materials, such as measurements of surface electroplating and coating, as well as stress, strain, crystal size, thermal conductivity, and magnetoconductivity. Once a rocket has been stored for a long time, or undergone environmental testing (or transportation), the nondestructive method of inspection and measurement can be used to inspect various defects, either exterior or interior, that may exist. The nondestructive technique is also required to apply to general assembly of a rocket at a technical testing site, launch site, or underground shaft, as well as inspection and monitoring before the rocket flight.

NONDESTRUCTIVE INSPECTION AND MEASUREMENT OF ENGINES

The nondestructive technique of inspection and measurement is quite successful in engines of liquid or solid fuel rockets. For example, the plan for nondestructive inspection of the carrier rocket Saturn V for Apollo spacecraft was quite strict at the beginning. New methods were developed besides the adoption of conventional ones. From the statistics, X-rays were used to inspect

2.4 kilometers of welded seams, 100 pieces of casting and forging, and 5000 transistors and diodes. In addition, supersonic inspection was used to check 0.64 kilometer of welded seams, 412 square meters of gluing area, and 8.05 kilometers of piping; the infiltration method was used to inspect 4.02 kilometers of welded seams; the eddy current method was used to inspect 9.65 kilometers of tubes; and supersonic inspection was used to check 1760 square meters of gluing area. For another example, the corrosion [-resistant] jet nozzle of a rocket engine is a multilayer structure made by gluing a nonmetal honeycomb and corrosion [-resistant] sleeve. The inspection and measurement means use a kind of microwave-sound system in an inspection instrument. The microwave method is mainly used to inspect separation of adhesion between the corrosion-resistant sleeve and the exterior plate of the honeycomb in the middle, as well as the separation of layers in the interior. The knocking method (judging from the sound) is used to inspect defects of the exterior plate and cores.

The quality control of a solid-fuel rocket is more complex. The components to be inspected are mainly the shell, jet nozzle, and engine after filling with solid fuel. All the superhigh-strength steel materials used in a solid-fuel rocket engine should be supersonically inspected to check whether there are layer separation and cracks, and all welded seams are inspected with highly sensitive X-rays; the magnetic powder and infiltration methods are used to inspect surface cracks as well as the cylinder and sealed cylinder head after heat treatment and hydraulic testing. The supersonic, microwave, infrared ray and corona discharge methods are used to inspect the reinforced plastic shell as well as the adhesion separation of shell boundaries after wrapping and adhering with a thermal insulation layer. The operating environment of a jet nozzle is under the greatest strain; therefore the quality control is strict for raw materials, supplies, and various work processes to inspection of the finished product.

After the solid propellant is poured into a rocket engine, inspections should be conducted on the following parts and components; separation of adhesion between the shell and insulating layer, between propellant and covered layer (insulating layer), and between insulating layers of the engine head

(tail component), interior defects and cracks (on internal surface) of the propellant column, separation of adhesion between artificial adhesion separating plate and propellant, pits, crevices, and corrosion and rust spots on shell exterior; also inspected are crevice traces on engine cover, jet joints, other joints, flange screw threads, bolts, sealed rings, and aprons, as well as internal cracks. The most difficult inspections are on separation adhesion of multilayer boundaries inside the solid-fuel engine and interior of propellant column, so there are various methods, such as visual inspection, knocking, supersonic and X-ray photographic inspections as the conventional means. In addition, new methods are developed, such as supersonic holography, neutron photography, microwave, and infrared heat imaging techniques. One of the common methods is the use of a linear accelerator to produce high energy rays for inspection of adhesion separation of large solid-fuel engines and cavities in the propellant column, as well as crack defects. The microwave method is used to inspect interior gas bubbles, separation of layers, metal impurities inside the composite materials (such as nonmetals and reinforced plastics), cavities in the propellant column (of the engine), and adhesion separation between the propellant column and the covered layer (insulating layer). The adhesion separation of the insulating layer inside the joint of the first-stage submerged nozzle and combustion chamber of the Polaris A_3 used the microwave inspection method. The method was also used in inspection of adhesion separation of the second stage steel shell engine. The smallest detectable diameter of the adhesion separation area is 150 millimeters between the covered layer and propellant; however, the engine should be warmed up during inspection before cooling down. In practice, various methods of inspection are used to compensate and check one another for an overall evaluation.

Generally, the nondestructive inspection methods used on rockets are a collection of nondestructive inspection techniques. Both now and in the future, the nondestructive technique is necessary to higher product reliability and quality control in the space industry.

At present, the nondestructive inspection technique is developing toward automation, miniaturization, and quantization. The various types of inspection devices are being more and more perfected and displays of defects are more

and more in the form of images. We can expect that with the progress of large integrated circuits and computers, especially the generalization of micro-computer applications, the development pace of the nondestructive inspection technique on rocket will be considerably quickened.

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